

AN ADVANCED NEUTRON RADIOGRAPHY SYSTEM

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INTRODUCTION

The Stationary Neutron Radiography System (SNRS) is located on McClellan Air Force Base, a government owned site of 2600 acres, located approximately five kilometers northeast of Sacramento, California.

The SNRS provides McClellan Air Force Base with the capability of neutron radiographing a wide variety of aircraft components. The facility has four radiography bays and consequently four beams of neutrons for radiography purposes. All four bays are capable of using radiography film techniques, but bays one, two and three are equipped with, and will normally use, electronic real-time imaging devices.

The SNRS facility consists of two major systems:

1. Nuclear reactor.
2. Radiography systems.

The basic design of these systems is covered in References 1 and 2. This paper will briefly describe the major systems but concentrate on the actual performance obtained.

OPERATIONAL CONCEPT

The primary mission of the SNRS is to perform neutron radiographic inspections of aircraft components to detect moisture and corrosion. The aircraft components come into the SNRS from a number of sources, repair shops to verify repair done was proper, the aircraft line to perform initial inspections and finally, the supply system to verify component can be returned to service.

The SNRS was designed to perform a high-throughput production type operation. This is accomplished by three groups within the facility. The reactor operations group operates and maintains the reactor and building systems. The minimum reactor operating crew consists of one reactor operator and one senior reactor operator within the facility operations area any time the reactor is operational. The health physics group is responsible for all radiation safety functions within the operations area and open and close all radiography bay doors. They also

provide radiation safety coverage for all reactor related maintenance operations. The minimum staffing during reactor operation for the health physics group requires at least one health physics technician in the operations area. The radiography group is responsible for preparing all components for inspection, inspecting the components, removing the components from the bays and finally removing the components from the operations area. The minimum staffing for the radiography group consists of two radiographers per bay. Therefore, during a typical one-shift operation the minimum number of personnel involved if all bays are running would be eleven people.

The reactor typically runs for 7-8 hours daily, five days a week. It normally takes 1-1.5 hours from the time a cart is introduced into the bay until the cart leaves the bay. This correlates to inspecting approximately 46 m² (500 ft²) per day.

SNRS Reactor

The SNRS reactor is a standard design 1000 kW, natural convection-cooled TRIGA reactor with the graphite reflector modified to accept the source ends of the four neutron radiography beam tubes which terminate in four separate radiography bays. The reactor is capable of both pulse and square-wave operating modes. The reactor is located near the bottom of a water-filled aluminum tank 2.1 meters (7.5 ft) in diameter and about 7.6 meters (25 ft) in depth. The control rod drives are mounted at the top of the tank on a bridge structure spanning the diameter of the tank. The reactor is monitored and controlled by state-of-the-art computer-based instrumentation and control systems featuring color graphics, self-calibration, and automatic logging of vital information.

The SNRS reactor fuel is a solid, homogeneous mixture of uranium-zirconium hydride alloy with 8.5% by weight of uranium enriched to less than 20% U-235.

Reactor criticality was achieved on January 20, 1990, with 63 standard TRIGA fuel elements, three fuel followed control rods and one air followed control rod.

On January 21, 1990, the excess reactivity of the core was adjusted and the worth of the control rods were measured. The final reactor configuration is as follows (G-Ring Grid Plate):

Fuel Elements	75
Graphite Elements	40
Fuel Followed Control Rods	3
Air Followed Control Rods	1
Excess Reactivity	\$5.15

RADIOGRAPHY SYSTEMS

Radiography Bays

There are four radiography bays configured around the reactor with concrete walls 1/2 to 1 m (2-3 ft) thick (see Figure 1). In Bays One, Two and Three, remotely controlled robotic positioning systems (described in Section 3.0) manipulate components in the neutron beam during real-time radiographic scanning. In Bay Four, high resolution film radiography is performed on smaller aircraft components, including pyrotechnics.

The largest of the four radiography bays is Bay One. Bay One is approximately 21.6 m (71 ft) long, 9.7 m (32 ft) wide and 11.5 m (38 ft) deep. This bay is used for radiography of very large aircraft components, such as F-111 wings and stabilizers.

Bay Three is the smallest radiography bay. It is 7.3 m (24 ft) long, 6 m (20 ft) wide and 4.9 m (16 ft) deep. Bay Three is utilized for the radiography of highly curved components due to the space restriction.

Beam Tubes

There are four neutron beam systems; one for each of the four radiographic bays. All four beams are capable of simultaneous operation. The neutron apertures, located at the edge of the reactor graphite reflector, are replaceable and constructed as shown in Figure 2. Aperture change-out is accomplished by remotely removing the in-tank section of the beam tube and replacing it with one of desired aperture.

The beam tube collimators are specifically designed to collimate the beam all the way to the radiography bay. The collimator construction is shown in Figure 3.

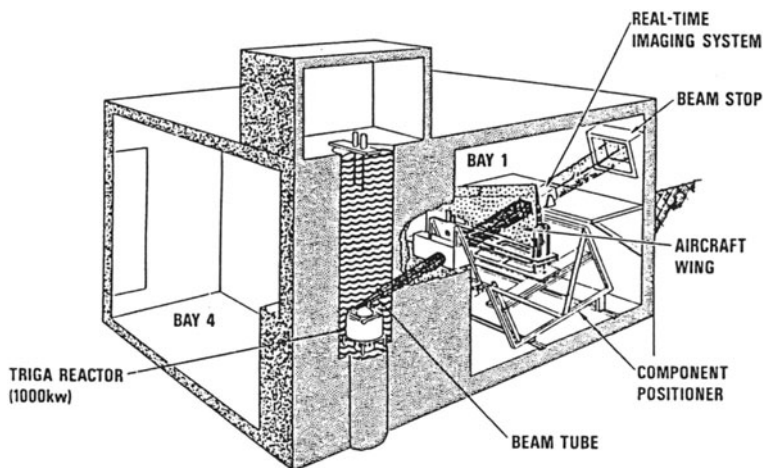
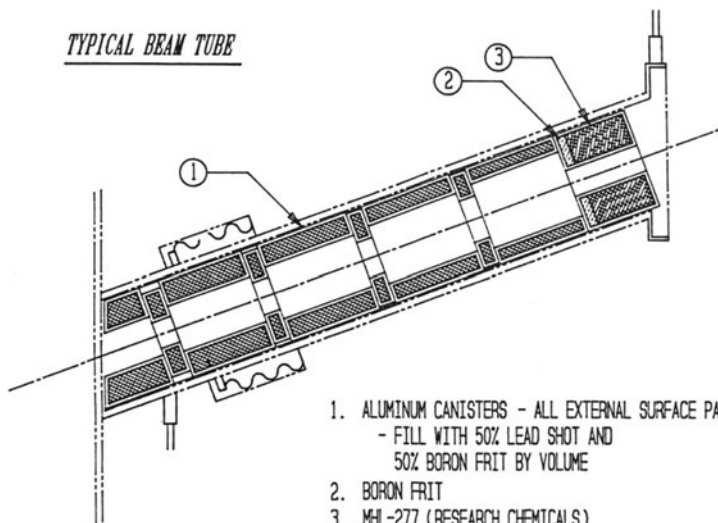


FIGURE 1

Robotic Components Positioning Systems

The Robotic Component Positioning System (CPS) within Radiography Bay One (CPS-1), (Figure 1), weighs approximately 30 tons and is the largest of the three positioning systems at the SNRS. Although many different aircraft components can be fixtured on to CPS-1, it's primary purpose is the remote movement of an entire F-111 wing through the neutron beam. CPS-1 repositions the wing accurately to one-quarter of an inch during inspections, allowing "before" and "after" comparisons of images.

TYPICAL BEAM TUBE



1. ALUMINUM CANISTERS - ALL EXTERNAL SURFACE PAINTED WITH GADOLINIUM PAINT
- FILL WITH 50% LEAD SHOT AND
50% BORON FRIT BY VOLUME
2. BORON FRIT
3. MHL-277 (RESEARCH CHEMICALS)

FIGURE 2

TYPICAL INSERT

MATERIALS LIST

1. REFLECTOR INSERT BODY
- ALUMINUM
- GRAPHITE
2. GRAPHITE END PLUG
3. BISMUTH CRYSTAL
4. ALUMINUM SPACER
5. GRAPHITE SLEEVE
6. BORON CARBIDE APERTURE
7. LEAD CADMIUM SHIELD
8. LEAD CADMIUM SLEEVE
9. LEAD SHOT AND BORON FRIT
IN AN ALUMINUM CANISTER

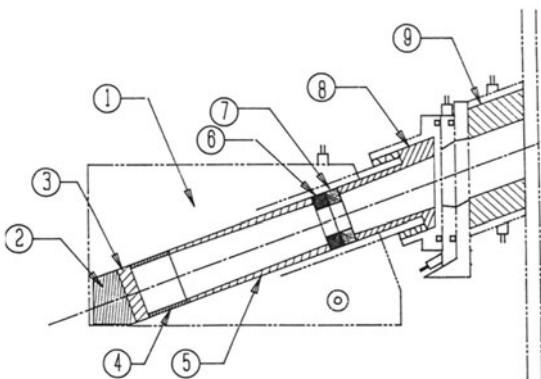


FIGURE 3

The X-axis movement is perpendicular to the beam and in the long direction of the radiography bay. The Y-axis provides vertical motion perpendicular to the beam. The Z-motion is along the beam direction. Yaw is a rotation about the Y-axis in the X-Z plane and pitch is a rotation about the X-axis.

The Component Positioning System within Radiography Bay Two (CPS-2) is similar to CPS-1, only with smaller dimensions proportional to the small size of the bay. Future plans call for the installation of CPS-3 within Radiography Bay Three by early 1991. Bay Four has no robotic positioning system as it is dedicated to film radiography.

Real-Time Imaging Systems

Although film imaging within Radiography Bay Four provides high resolution radiographs, the SNRS design concentrates on real-time radiography. Use of real-time imaging allows for digital enhancement of the radiographic images as well as high throughput of components when coupled with the robotic positioners.

The real-time imaging systems at the SNRS use a Thompson CSF tube, an internal gadolinium-oxy-sulfide scintillator, and a Plummicon camera. Radiography is performed with an operator viewing the images while the component is moved in an automatic scan mode. Maximum scan speed is two inches per second, while typical scan speed is one-half inch per second, enabling an entire F-111 wing to be scanned in less than two hours. The operator may, however, manually interrupt the scan for more detailed interrogation in local areas if desired.

Scan images are stored on magnetic tape for comparison after component repair or subsequent inspections. If corrosion is shown earlier, but not to a degree requiring repair, it is important to compare the present image to the previous one to evaluate possible deterioration.

Radiography Results

The four radiography beams have been analyzed for intensity and radiographic quality. The results of these measurements are shown in Table 1.

Table 1

BAY	L/D	(250 kW)	NC%	ASTM E 545-86			R _{CD}
		THERMAL FLUX (n/cm ² *sec)		S%	LEG%	HEG%	
1	102	3.96 x 10 ⁶	70	.20	1.0	.40	3.8
2	104	4.57 x 10 ⁶	70	.40	0.8	.40	5.3
3	108	5.00 x 10 ⁶	72	.60	1.2	.40	4.7
4	104	3.85 x 10 ⁶	73	.40	1.5	.40	4.0

R_{CD} = Cadmium Ratio, NC = Thermal Neutron Content, S = Neutron Scatter Content, LEG = Low Energy Gamma Content, HEG = High Energy Gamma Content

CONCLUSION

The SNRS has been operating since January 20, 1990. The preliminary measurements indicate the facility is capable of producing high quality real-time and film radiography. The reactor is capable of providing a number of additional services including sample irradiations, in-core irradiations, in-core pneumatic rabbit system irradiations, nuclear hardness testing, pulse and square wave operation, and neutron activation analysis.

The robotic system for handling large aircraft parts has been shown to be capable of handling 46 m² (500 ft²) of parts per day. The radiographic quality both real-time and film are excellent.

The SNRS is capable of providing a high quality inspection of aircraft parts and will result in a large cost saving for the Air Force.

REFERENCES

1. A.A. Weeks, D.L. Newell, and C.C. Heidel, The Stationary Neutron Radiography System, TRIGA Conference, Austin TX, 1990.
2. C.C. Heidel and W.J. Richards, Startup Data For The Stationary Neutron Radiography System, TRIGA Conference, Austin TX, 1990.